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Second-generation biofuel (SGB) in Southeast Asia via lignocellulosic biorefinery: Penny-foolish but pound-wise

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ABSTRACT

Over optimistic projects on crop-based biofuel, especially first generation biofuel (FGB), in Southeast Asia have hampered future development of biofuel. In this study, second generation biofuel (SGB) was introduced to substitute crop-based biofuel in Southeast Asia. This work suggests that the development of lignocellulosic biorefinery be designed as a package for SGB and by-products that is divided into stages. Although biorefinery projects are capital intensive in the early stage, the infrastructures and transportation network built up in rural regions can provide cross border trading routes, connecting towns and villages as well as improving the living standards of rural residents. In addition, it reduced pollution problem by treating the biomass in proper ways to prevent illegal burning. Hence, it is essential that Southeast Asia chart its direction clearly to create self-sufficient community by utilizing the biomass resources. By setting biorefinery as a development goal, Southeast Asia can illustrate a blueprint for positioning its future on the grounds of renewable energy.

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1. Introduction: over optimistic biofuel projects in Southeast Asia

Ensued by idealization, the introduction of biofuel to the world is apt to connote a promising energy resource to mankind in the future. Indeed, the associated risks and ventures have been covered without empirical justification, especially for palm oil and Jatropha-based biofuel in Southeast Asia. It is noteworthy that the production of palm-biodiesel using edible sources as feedstocks has been fraught with uncertainties. The outperformance of crude palm oil prices against fossil fuel, which has made biodiesel relatively more expensive, has rendered the shutdowns of six out of eleven Indonesian palm-based biodiesel plants with the rest operating below 5% of their capacity [1]. Moreover, as a consequence of feedstock discontinuity, Malaysia, which outlined its National Biofuel Policies grossly based on palm-based biodiesel, has failed to achieve its 5% target. Likewise, in Thailand, the price surge of sugar cane in the market has resorted sugar cane-based bio-ethanol plants to operating at merely 70% of their production capacity [2]. Thus, food crop-based biofuel is not necessarily a good option for renewable energy.

Instead of food crops, Southeast Asia governments have been reckoning Jatropha as an alternative feedstock. However, it is much questioned for its carbon balance as it triggers deforestation and

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land-use change. Without considering cultural, social and political landscapes, it is irresponsible to emphasize the potential of Jatropha. By means of a wider socio-political scope, policies to transform arable land that is suitable for food crops into Jatropha cultivation sites are not only intellectually irresponsible, but they also bring disasters to smallholders. In Myanmar, massive transformation from food crops to Jatropha plantation has caused starvation in rural areas [3]. This is because the life cycle and harvesting techniques of Jatropha fruits are still largely in their infancy. Furthermore, preventive measures for marginalization and social disarticulation are not adequately catered. The long-term adverse effects to health are also not taken into consideration when this poisonous plant was promoted. The weed-like behavior of Jatropha makes it an invasive species which may interrupt local biodiversity in a large-scale cultivation without proper planning.

On top of that, the most crucial reason for biofuel policies failure is attributable to the flaw in scientific understanding. As revealed by REFUEL project in the EU, first generation biofuel (FGB) will gradually be substituted by advanced biofuel [4]. Although some may rate FGB as a precursor for second generation biofuel (SGB), it is irrelevant in both technical and economic terms. The technologies for FGB and SGB are distinct significantly, especially for lignocellulosic bioethanol and Fischer–Tropsch biodiesel. It is hence predictable that trailing the trend in the EU for the development of FGB in Southeast Asia is impractical. In other words, Southeast Asia has not readied itself for a massive production of FGB. Unfortunately, it will neither bring any sustainable development to the countries in the future. Worse still, the over-produced energy crops will eventually become a huge economic barrier to Southeast Asia when the world is changing their trend to the development of SGB. Southeast Asia, however, does not have the capital and strength to be involved in such development. In fact, the industry is so fragile that it may collapse easily anytime with fluctuations of petrol and feedstock prices, as well as economic instability.

On the other hand, when Indonesia realized that it is not economically feasible to produce Jatropha biodiesel, the program was discarded. Malaysia and Thailand suffer the same fate in pursuit of global trend in promoting jatropha biodiesel, after which the subsidies and incentives were wasted ultimately. The project outcomes, which failed to meet expectations owing to haphazard planning and imprudent policies, have subjected the policymakers to disgrace. Therefore, the authors would like to introduce production of SGB via lignocellulosic biorefinery as a better option for Southeast Asia in the following section.

2. Development of SGB: penny-foolish but pound-wise

Despite the pinch experienced in developing palm oil and Jatropha biofuel, Southeast Asia is not facing stark choices. Past failures indicate that a more reliable feedstock is indispensable to ensure sustainable development of renewable biofuel. Policymakers must be well aware that the production of biofuel which involves unfavorable changes to land, society and economy is not commercially viable. In this context, lignocellulosic residues from agriculture are more suitable raw materials for the production of biofuels, such as second generation bio-ethanol and Fischer–Tropsch synthetic diesel. As opposed to the old saying, “penny-wise and pound-foolish”, the investment and development in SGB can be implemented via a “penny-foolish and pound-wise” strategy if compared with the first generation. This description denotes the concept whereby a small amount of investment appropriated for FGB should be sacrificed to envision a larger amount of return in the future by investing into SGB. Nevertheless, Southeast Asia governments are currently refraining themselves from investing into advanced biofuel technologies such as SGB on account of its capital intensive nature. Besides that, SGB industry is still in its infancy compared with commercialized food crop biofuels. There are, however, previsions from experts that SGB will eventually overtake FGB in not more than 10 years [4]. The foreknowledge can be supported with the failure faced by the region in the FGB sector at present. In this respect, this article is meant to elaborate on this issue from several aspects with the ultimate goal of raising awareness among policymakers to revise the derailed biofuel policies.

2.1. Lignocellulosic feedstock

2.1.1. Pollution from open burning

Before delving into the feasibility of SGB, the availability of lignocellulosic feedstock in Southeast Asia has to be evaluated properly. First of all, it is noteworthy that Southeast Asia is naturally bestowed with substantial forestry and agricultural resources. Annually, the region produces a large quantity of residues from agricultural and logging sectors, creating undesirable pollution problems. Worse still, farmers in the rural areas tend to burn these residues openly. On the other hand, big plantation operators normally use these residues as fuel to generate steam although they are not an ideal fuel source. This is due to its high moisture content which, upon burning, liberates greenhouse gases and particulate matters that engender adverse effects on the residents in the neighborhood. Thus, there is a need to better utilize these lignocellulosic biomasses by, for example, converting them to SGB.

2.1.2. Biomass availability from agricultural industry

Based on our previous study reported in the literature, it was found that in the year 2007 alone, the palm industry in Malaysia generated more than 91 million tonnes of lignocellulosic residues in the form of fronds, empty fruit bunch, trunks, shells and fibers. By taking the average composition of lignocellulosic residues, it would translate to 18 million tonnes of cellulose, 10 million tonnes of hemicelluloses and 10 million tonnes of lignin [5]. After Indonesia has overtaken Malaysia as the largest producer of palm oil in the world, these figures are expected to be at least twofold larger. To date, both countries dominate the palm oil market in the world, with more than 88% share in production [6].

In addition, the sugar cane industries in the Philippines, Thailand, Indonesia and Vietnam also produce a large amount of residues. With more than 150 sugar mills in the region, approximately 34 million tonnes of bagasse is generated yearly [7]. On the other hand, 19 million tonnes of rice husks (22% of paddy) and 34 million tonnes of paddy straw (40% of paddy) are produced per annum in Thailand, Indonesia, Malaysia, the Philippines and Vietnam [8,9]. Out of 15 million tonnes of coconut produced in the Philippines, 34% of the total biomass remains as residues, which translate to 5 million tonnes of coconut shells and husks generated annually [5,10]. Apart from the agriculture sector, the wood industry also generates 30 million m^3 of lignocellulosic residues annually, which is equivalent to approximately 17 million tonnes in weight [8,11]. Table 1 summarizes the availability of various kinds of residues which are potentially convertible to SGB. Based on the composition of the respective residues and using conventional bioethanol production technology, the quantity of second generation bioethanol generated is calculated using general Eq. (1). Eqs. (2) and (3) give the specific equations for cellulose and hemicelluloses, respectively.

$$\text{bioethanol yield} = \text{mass} \times \text{theoretical yield} \times \text{glucose recovery} \times \text{fermentation efficiency} \tag{1}$$

Table 1
Estimation of SGB potential in Southeast Asia.

Commodity residues	Quantity ($\times 10^6$ tonnes)	Moisture content (%)	Dry weight ($\times 10^6$ tonnes)	Cellulose (%)	Hemi-cellulose (%)	Cellulose ($\times 10^6$ tonnes)	Hemi-cellulose ($\times 10^6$ tonnes)	Bio-ethanol ($\times 10^6$ tonnes)	References
Oil palm fronds	94	60.0	56	62.3	24.2	35.1	13.6	13.4	[15]
Empty palm fruit bunch	36	65.0	23	54.4	28.0	12.7	6.6	5.2	[16]
Oil palm fibers	22	42.0	9	20.8	38.8	1.9	3.6	1.4	[17]
Oil palm shells	9	7.0	1	20.8	22.7	0.1	0.1	0.1	[18]
Oil palm trunks	22	75.9	17	41.2	34.4	6.9	5.7	3.3	[19]
Sugar cane bagasse	34	50.0	17	50.0	25.0	8.5	4.3	3.5	[20]
Paddy straw	34	11.0	4	35.0	21.0	1.3	0.8	0.6	[21]
Rice husks	19	9.0	2	35.1	20.9	0.6	0.4	0.3	[22]
Coconut husks	5	11.5	1	44.2	12.1	0.3	0.1	0.1	[23]
Wood residues	17	12.0	2	46.3	28.3	0.9	0.6	0.4	[24]

$$\text{bioethanol from cellulose (tonnes)} = \text{cellulose (tonnes)} \times 0.5111 \times 0.76 \times 0.75 \quad (2)$$

$$\text{bioethanol from hemicellulose (tonnes)} = \text{hemicellulose (tonnes)} \times 0.5175 \times 0.90 \times 0.50 \quad (3)$$

These equations were taken from our previous study reported elsewhere [5]. In accordance with other studies reported in the literature, the current process can produce lignocellulosic bioethanol at a net energy value ranging from 1.5 MJ/L to 19 MJ/L using different technologies [12,13]. With the assumption that all available biomass is completely utilized for the bioethanol industry, an optimal net energy of more than 6.8×10^8 GJ can be generated per annum with contemporary technologies. The amount of bioethanol produced constitutes more than 11% of the total energy (6.25×10^9 GJ/year) demand in Southeast Asia [14]. With technology improvements and scaling up factor, the contribution of lignocellulosic biofuel will be further expanded. Fischer–Tropsch synthetic diesel, which is highly remarked as the future advanced fuel, was predicted to enter the market by late 2020 [4]. This shows that the utilization of lignocelluloses still has a large room for improvement.

2.1.3. Economic benefit over crops based biofuel

The key difference between crop-based biofuel and lignocellulosic biofuel is the feedstock availability. Previously, policymakers were misled that crops are ideal source for biofuel owing to vast land availability and easy feedstock accessibility. In reality, large-scale conversion of lands into fuel crops plantation is not economically feasible. Firstly, not all marginal lands are suitable for plantation of energy crops. Although the energy crops might survive in the area, the yield is somewhat unpredictable on account of different local climates and soil properties. For instance, Jatropha and sweet sorghum shed leaves as an adaptive measure in dry areas to avoid excessive water loss. As a result, the growth rate decelerates, rendering fruiting inconsistent [25]. Thus, so as to improve the yield in marginal lands, high volume of water and fertilizers are required. This eventually leads to higher production cost and is likely to cause water shortage and agrochemical pollutions. On the contrary, the production of lignocellulosic biofuel which is not susceptible to land-use changes is free from these economic barriers.

Apart from that, the economic feasibility of converting edible crops into fuel is largely dependent on feedstock price. If a large quantity of food crops is used for the production of biofuel, its high demand will raise food crop price and imbalance in the food supply chain. In the long run, this will cause food crisis in that region and subsequently lead to social instability which might give rise to a huge impact on the economic sector. Conversely, lignocellulosic residues have always been classified as agriculture wastes which have negligible economic value. Therefore, converting waste to valuable biofuel is regarded as a strategic move economically. Besides that, the production of SGB can be easily integrated into the agriculture sector. Essentially, residues can be collected to biofuel processing units without causing interference to the primary agro-industry. On top of that, in remote rural areas, SGB is a potential substitute for expensive diesel and kerosene as fuel sources.

2.1.4. Market penetration of SGB

From the authors' point of view, the root causes of biofuel lurch in Southeast Asia are incomprehensive scientific understanding and inaccurate positioning. In fact, according to the assessments conducted in the EU, the overall concept of biofuel development is conceivable [26–28]. As discussed in the previous section, the displacement of FGB by SGB is almost definite but with an uncertain timeline. However, the penetration of SGB as a replacement of FGB is largely influenced by policies [26]. Different paths taken by a particular country will determine its future biofuel mix. Owing to a big difference in the geographical and climate conditions, the roadmap used in the EU may not fit in Southeast Asia. Therefore, it is very important that Southeast Asia chart their unique roadmap in their journey towards the biofuel era.

As reported by REFUEL, FGB will dominate the market in the early stage subsequent to the implementation of biofuel policies in the EU. Low-cost FGB will continue to impede SGB from entering the market with its lower price. However, by virtue of significant negative environmental and social impacts brought about by FGB, SGB will gradually penetrate the market and ultimately supplant FGB. By means of BioTrans model, it was predicted that FGB will not be able to maintain domination in the biofuel market for more than 10 years owing to its inherent limitations [28].

Undisputedly, technology barrier has always been a blockade that stops policymakers in Southeast Asia to make investment and commitment towards the development of SGB. Nonetheless, it must be hereby emphasized that the development of emerging technologies, such as in the case of SGB, will require strong support and funding from the local government. Therefore, sufficient budget must be allocated to stimulate the development of this technology through research and development which, in most cases, will bring in good return in the long run. In fact, it is only through technological learning via research and development can the technology for SGB be improved over time to make it economically feasible. At the early stage, a precursor should be established before SGB comes into play. A strategic move is to utilize the agriculture residues in a systematic way. This will facilitate building up of a logistic network that is useable for SGB feedstock collections in the future. There are several ways to extract energy from lignocellulosic residues, such as gasification and co-generation. Relevant development will induce further utilizations of biomass and ulti-

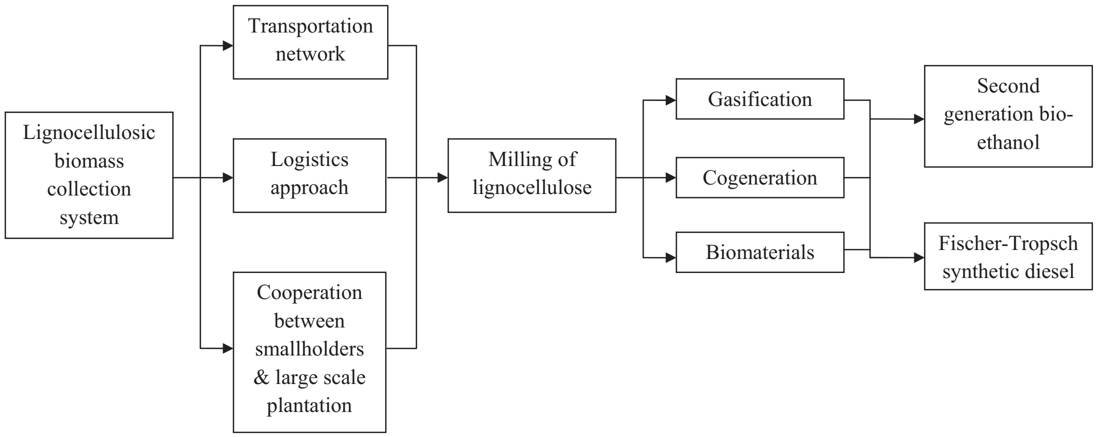

Fig. 1. SGB development package in Southeast Asia.

mately resort to the production of SGB. The facilities built to handle residues can be modified for the use of SGB production in the near term [29]. Therefore, by the time the EU is shifting towards SGB, Southeast Asia would have been able to provide a steady platform with experience and facilities in processing the residues.

2.1.5. Economic effect on Southeast Asia

The introduction of EU biofuel policy actually provides Southeast Asia with an opportunity to initiate its SGB development. It was reported that the EU will import more biofuel with the existence of 10% target in the aggregate for biofuel substitution as promulgated in their renewable energy policy. [33] In addition to this, when the EU fully implements this strategy, biofuel used must achieve at least 35% GHG saving as compared with conventional fossil fuel. Only then will SGB have a clear advantage over FGB. In this scenario, Southeast Asia will have a better role to play with its enormous lignocellulosic resources. It is believed that the new industry will definitely attract foreign investments and create various types of employment. This is of utmost importance in stimulating development of rural areas especially in those poverty-stricken countries. Furthermore, by means of capital and technology transfer, job vacancies that require higher academic qualifications are created. This trend will drive the education in the area to fulfill the labor demand. Compared with previous biofuel projects, lignocellulosic industry is more promising and is accompanied by lower risk. Although intensive capital has to be appropriated in the early stage, the infrastructures built can be of multipurpose use. Besides that, the logistic system for collection of agriculture residues from smallholders creates a prototype for transportation network in rural or marginal areas, thereby facilitating cross-border trading. Therefore, in a long-term consideration, the development of SGB project can be envisioned as a package designed for rural regions especially in poorer countries. The proposed package for SGB in Southeast Asia is illustrated in Fig. 1.

3. Challenges and opportunities In Southeast Asia

In the past few years, biofuel has been deemed the bedrock of energy security in Southeast Asia. Nevertheless, there is underlying pessimism which is attributable to the technical immaturities and economic barriers that can resort ASEAN countries to underperforming status. This is partly reflected by the phenomenon in which more than one third of the population has yet to have access to electricity (ASEAN, 2007). Highly uneven economic prosperity and distribution of wealth on a geographical basis greatly increase the resistance to regional cooperation. Moreover, considerable gap between technical potential and inter-regional utilization of bio-energy will lead to conflicts and arguments, especially during technology transfer. In spite of that, the solution to bio-energy puzzle will largely depend on policymakers as to whether to remain in status quo or to take a proactive move geopolitically. However, the associated complexity might demand more arduous effort in energy and economic integration.

Despite local encumbrances, the potential of lignocellulosic residues remains uncertain from some aspects. On account of different types of techniques and ways of utilizing biomass, it is difficult to estimate the future scale of the processing plants. The output of these plants was reported in the literature, but the figures still require more justifications to consider a wider scope [30,31]. Hellmann and Verburg [32] reported that modeling of biofuel economics is complex since the industry is highly subsidized and not solely dependent on economic ground. Hence, this extrudes the importance of precursor projects to be launched to serve as rudiments for the development of advanced SGB.

In a nutshell, harnessing energy from biomass is difficult in terms of not only technologies and policies, but also enforcement and practicality. Without a clear vision, strong management, consistent revision and policy enforcement, sustainable development of the energy sector is merely phrase-mongering. On top of that, diverse resources may result in disparities of bio-energy development among regions and countries. As substantiated by history, incongruous resource distribution may cause social and political instability. It has been a crucial issue when the poor smallholders of energy crops are suffering from the squeeze put on by the consolidators or even corrupted agencies. Therefore, there must be laws in place to ensure that the rights of these smallholders are well taken care of in all aspects.

However, challenges and opportunities are seamlessly interconnected. By removing the barricades against regional bio-energy integration, relevant strategies can be planned painstakingly to bring about the proliferation of bio-energy production and form a connection between smallholders in rural areas and authorities of large-scale bio-refineries. Eventually, all inevitable obstacles can be hurdled with the high caliber and prudence of leaders, as well as cooperation of the people. Instead of perceiving biofuel as a ready source of energy, more practical and careful attitudes in developing the industry should be adopted.

4. Conclusion

Despite the muddled situation of first generation biofuel market in Southeast Asia, SGB is still predominant over FGB to date. Introduced without performing a holistic evaluation, first generation biofuel has associated itself with inaccurate positioning

which stems from over-optimistic forecast and policymakers' excessive confidence, thereby resorting to the "white elephant" phenomenon. From the authors' point of view, appropriating budget for SGB development would put Southeast Asia on a proactive position in the renewable energy sector. In spite of the costly investment in the early stage, SGB is very likely to bring immeasurable benefits to the region. It can be designed as a development package for rural areas by breaking the plan down into different stages. In the early stage, a massive construction of infrastructure is necessary to effectively collect biomass from plantations. These investments will eventually form a network in rural or marginal areas, provide cross-border trading routes, connect towns and villages, as well as improve the residents' living standards. When the timing is right, SGB will come into the global biofuel market. As a more sustainable and reliable biofuel, SGB provides Southeast Asia not only economic returns, but also a cleaner environment and better energy security. Fundamentally, coherent voice from ASEAN members is the key aspect not only to ensure the regional energy security but also to expand their economic potential in global bio-energy market.

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